Haptic Stiffness Identification and Information Transfer

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Abstract

This experiment investigated static information transfer (IT) in a stiffness identification experiment. Past research on stiffness perception has only measured the Weber fraction. In many applications where haptic virtual environments are used for data perceptualization, both the ability to discriminate stiffness (Weber fraction) and the number of correctly identifiable stiffness levels (2^{IT}) are important for selecting rendering parameters. Ten participants were asked to tap a virtual surface vertically using a custom-designed haptic force-feedback device and identify the stiffness level. Five stiffness values in the range 0.2 to 3.0N/mm were used. The virtual surface was modeled as a linear elastic spring and exerted an upward resistive force equaling the product of stiffness and penetration depth whenever it was penetrated. A total of 250 trials were collected per participant. The average static IT was 1.57 bits, indicating that participants were able to correctly identify about three stiffness levels.

Background

- The last decade has witnessed rapid advancements in incorporating haptic feedback into data visualization systems (e.g., [1-7]). Although there exist many guidelines on how information should be displayed visually (e.g., [8, 9]), the design of “haptic glyphs” is still in its infancy.
- To represent a discrete variable with a haptic signal, a knowledge of channel capacity – the maximum amount of information that can be transmitted through the signal – is required. From the information transfer measurement, we can estimate the number of signal levels that can be correctly identified, which translates into the number of categories a particular haptic signal can represent without confusion.
- The goal of the present study was to establish the information-transmission capabilities of stiffness through the sense of touch.

Methods

Participants

- Ten participants (5 males and 5 females, age range 19-61 years old, average age 29 years old)

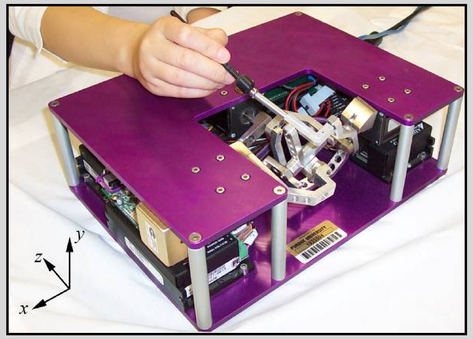
Apparatus

- Mini-stick
  - 3-Degrees of Freedom
  - Nominal 1μm resolution
  - Force commands updated at 2kHz
- User interacts with the virtual objects rendered by the ministick using a stylus

Stimuli

- Tested stimulus levels:

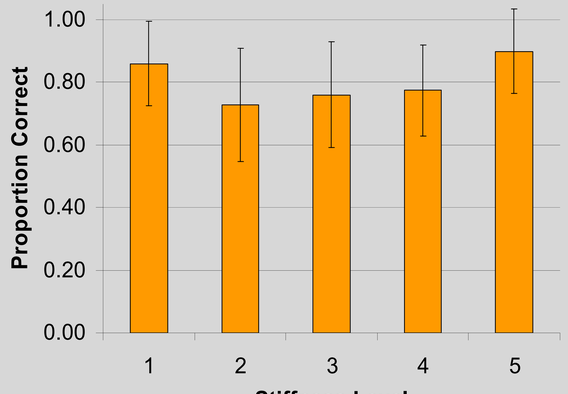
  0.20, 0.39, 0.77, 1.52, and 3.00 N/mm



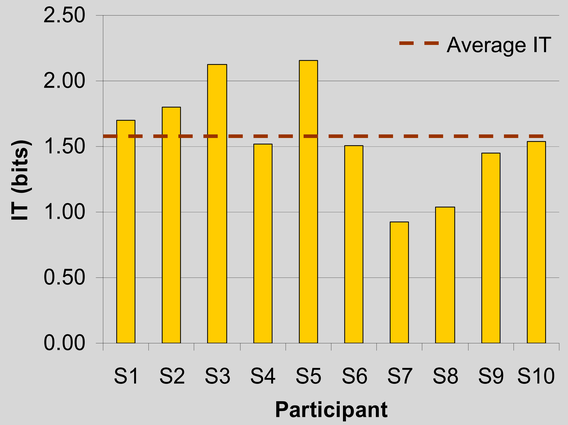
Procedures

- One-interval five-alternative forced-choice absolute identification procedure.
- The participant was instructed to tap a horizontal virtual surface to gauge its stiffness.
- Limited training was provided so the participant could feel the stimulus alternatives and associate them with the 1-5 response labels.
- Each participant completed a total of 250 trials per experiment, split across two runs of 125 trials each. A break of at least 15 minutes was enforced between runs to avoid muscle fatigue.
- The participant responded by pressing the number key 1, 2, 3, 4, or 5 on a keyboard. Trial-by-trial correct-answer feedback was provided.

Results



- Item analysis suggested that, on average, participants had comparable levels of accuracy for all stiffness levels.



- One-way analysis of variance (ANOVA) did not reveal a statistically significant difference between the first and second runs.
- On average, the participants could only reliably identify 2-3 levels (Average IT = 1.57 ± 0.40 bits, 2^{IT} = 2.97 items) of the stiffness values in the range 0.2–3 N/mm.

Conclusions

- It was found that the participants could reliably identify 2 to 3 levels of stiffness
- Our results are consistent with the information transfers reported by earlier studies, which varied from 2-4 correctly-identifiable levels for haptic parameters.
- We recommend that designers of data perceptualization systems assign two stiffness (i.e., high and low) to represent categorical variables, with a possible third level (medium) added for more experienced users.
- In the future, we will investigate the channel capacities of other haptic parameters such as force-magnitude, viscosity, and mass.
- The results will contribute to the knowledge base for designing haptic building blocks in a scientific data perceptualization system.

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